Optimal Cost and Component Configuration Analysis of Micro-grid using SSO Algorithm

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***Abstract*—The efficiency and optimal size of a micro-grid can be evaluated through economic analysis. Optimization is crucial for the sustainable development and upkeep of a micro-grid from a financial perspective. The total cost of production can be lowered by taking advantage of available subsidies for things like capital, operations, pollution, and renewable energy, as well as satisfying a number of equality and inequality standards. The social spider optimization (SSO) method is an effective and versatile way to save money. In some cases, SSO is used in conjunction with other AI-based optimization techniques. In this work, we present a methodology for assessing the economic and environmental sustainability of grid-connected energy systems. The mathematical function of a micro-grid may consist of recycling the electricity generated each hour in relation to the resources available and storing the surplus in a super capacitor battery bank. Using a model developed for the Halishahar area of Chattogram, Bangladesh, we maximize the performance of a hybrid system consisting of photovoltaic cells, wind turbines, biomass, and a super capacitor battery. Solar panels, wind turbines, super capacitor batteries, and biomass are just some of the sustainable energy sources that the designers are thinking about. The area is estimated to consume roughly 107,150 MWh of electricity each year. We employ a social spider optimization strategy to determine which configuration settings will yield the lowest annual cost. More than a year's worth of electricity for Halishahar can be generated by this micro-grid. With this configuration, the LCOE for electricity is only 0.127 \$/kWh (dollar per kilowatt-hour). It's more effective at cutting carbon dioxide emissions than conventional power.**

***Keywords*—Social spider optimization, Biomass, Micro-grid, Energy management, Energy generation, Renewable energy.**

I. Introduction

Electricity is one of man's most basic needs because it is involved in practically every aspect of modern life. For this reason, reliable access to electricity is crucial. Despite the country's recent economic growth, many rural residents and islanders in Bangladesh still lack access to grid-connected electricity. Coal, oil, and gas supply most of Bangladesh's energy, but they also release greenhouse gases and other pollutants. Modern power plants use solar and wind energy to lessen their environmental impact [1]. Micro-grids, defined as a group of interconnected loads and scattered energy supplies inside clearly defined electrical borders, have gained popularity as a way to provide reliable and sustainable electricity in remote or off-grid areas [2]. One of the biggest challenges in micro-grid design and operation is arranging energy sources and storage devices to lower power generation and distribution costs.

This research proposes using a SSO algorithm for micro-grid component configuration analysis and cost optimization. In 2013, Erik Cuevas et al. developed a population-based algorithm called the Social Spider Optimization (SSO) that models the collaborative behavior of real-world social spiders [3]. SSO considers male and female search agents (spiders). We will use the SSO method to find the most cost-effective micro-grid configuration for short- and long-term planning horizons. This research may help build and operate micro-grids in many applications. As micro-grids become more popular, it's important to consider both their initial cost and their long-term economic viability. Cost-effective micro-grid-specific solutions can be created using optimization methods like the SSO algorithm.

This method can help mitigate the risks and fluctuations associated with renewable energy sources. Multiple studies evaluate the technical and economic feasibility of constructing a PV/Wind/Biomass/Super capacitor Battery system [4]. Current research seeks to find the most cost-effective and reliable ways to optimize micro-grid components to meet load requirements. Micro-grid complexity required optimal augmentation solutions. Social spider optimization (SSO) increases the micro-grid by finding the global optimum. Renewable energy is needed due to environmental consciousness. Micro-grids require a significant initial investment. Optimization may improve a renewable energy system's technical and economic efficiency. Reducing grid micro-components could lower installation and operating costs. SSO was used to plan and build Halishahar's micro-grid, to reduce cost and optimize component performance.

In comparison to analogous calculations, SSO is straightforward. SSO avoids overlap and mutation calculations. Social spider optimization directs issue space search using a performance meter or objective function, and it is beneficial for non-differentiated tasks. Response-based SSO results are real numbers, and with a constant answer, the number of dimensions can be determined. To improve system reliability, hybrid renewable systems sometimes use a controllable energy source like the grid. Social spider optimization helps find the best micro-grid parts arrangement to lower installation and running expenses.

II. Model of Micro-grid System

The processes involved in creating the micro-grid system diagram are shown in Fig. 1, along with the mathematical import and purpose of each sub-component. The system consists of solar photovoltaic (PV) panels, wind turbines, a biomass gasifier, batteries, and dual converters. Using an energy management plan with the SSO optimization model reduces LCOE and greenhouse gas emissions.

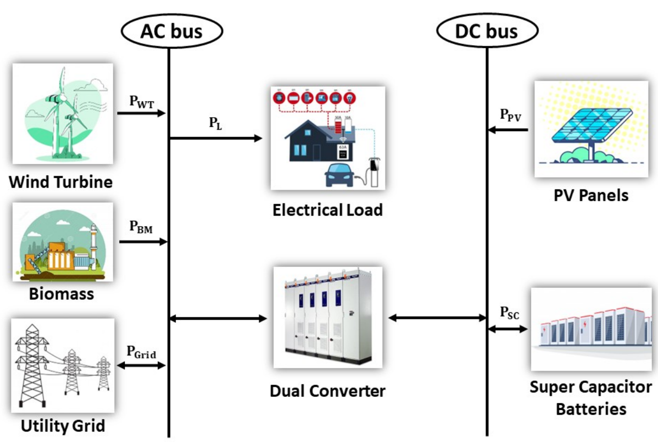


Fig. 1: Hybrid Power Generation System

Renewable energy sources like the wind turbines and solar panels seen in Fig. 1 help ensure that the world's energy needs can be met in the long term. Energy may be produced from solid bio-debris using biomass. During periods of high generation, excess electricity may be used to charge super capacitor batteries, and during times of low generation, the bank can be refilled by buying power from the conventional grid.

A. Wind Turbine Modeling

The wind turbines were designed using the quadratic model. Wind turbine power can be determined using the equation (1).

$$P_{wt}(t) = \begin{cases} 0 & V(t) \leqslant V_{cin} \text{ or } V(t) \geqslant V_{cout} \\ P_r^w & V_{rat} \leqslant V(t) \leqslant V_{cout} \\ P_r^w \left(\dfrac{V(t) - V_{cin}}{V_{rat} - V_{cin}} \right) & V_{cin} \leqslant V(t) \leqslant V_{rat} \end{cases} \quad (1)$$

The following formula describes the power output of a single wind turbine, where P_r^w is the turbine's rating, V_{cin} is the cut-in speed, V_{cout} is the furlong speed, V_{rat} is the rated wind speed, and V_t is the wind speed at the target height [5].

B. PV Panel Modeling

A solar photovoltaic panel's energy output may be calculated by adjusting the coefficients in the following equation (2).

$$P_{sol}(t) = P_r^s \frac{G_h(t)}{G_S} \Big[1 + k_t \Big(T_{amb}(t) + 0.0256 G_h(t) - T_S \Big) \Big] \quad (2)$$

The power rating of the solar PV panel is denoted by P_r^s, and the hourly solar radiation incident on the panel's surface is denoted by $G_h(t)$ (in W/m2). For incoming radiation at a standard incidence rate of 1000 W/m^2, indicated by G_S, the value of k_t is $-3.7 \times 10^{-3} (1/°C)$. The standard temperature is 25 $°C$, and the hourly ambient temperature is indicated by $T_{amb}(t)$. [6].

C. Boimass System Modeling

Biomass fuels include materials like wood, cow dung, leaves, twigs, and agricultural leftovers like straw and husk. The process of creating energy is a sort of energy conversion that makes use of technology to convert biomass resources into useful heat and electricity. Fig. 2 is a schematic depiction of biomass. The solid bio-debris is used as a feed-stock and transported to the devolatilization reactor in this system. Solid bio-debris is fed into the boiler via the top tunnel, as shown in Fig. 2 and the boiler started to heat up. The hottest part of the boiler is where solid bio-debris interacts. Each sector has its own cannon, and it fires different kinds of particles. The boiler works by causing the solid bio-debris to heat up when it combines with the synthesis gas. Steam is generated from the synthetic gas and sent upward via the boiler vessel and into the steam turbine. Electricity is created by a generator, which is powered by the spinning of a steam turbine. The heat from the boiler releases a quantifiable quantity of carbon dioxide into the atmosphere.

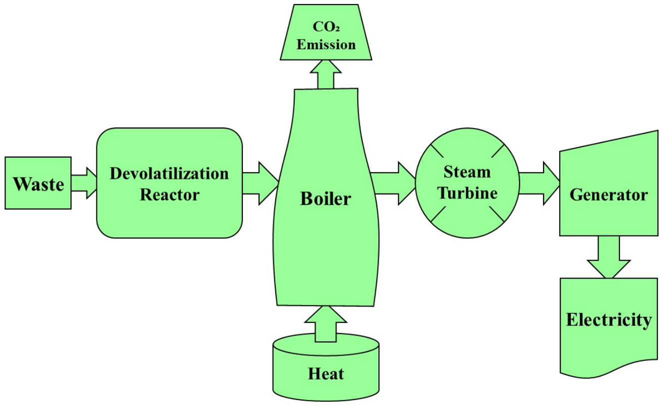


Fig. 2: Schematic Diagram of Biomass System [7]

The potential energy produced from biomass is denoted by the symbol P_{BM}, and can be calculated using the equation (3).

$$P_{BM} = \frac{Total_{BM} \times 1000 \times CV_{BM} \times \eta_{BM}}{8760 \times O_t} \tag{3}$$

The total organic materials of biomass is denoted by $Total_{BM}$, the calorific value of the organic material is denoted by CV_{BM} (≈20 MJ/kg), the biomass efficiency is denoted by η_{BM} and the number of operating hours per day is denoted by O_t [7].

D. Super Capacitor Battery Modeling

The model for the energy stored in the SC at any given time is shown in the equation (4).

$$E_{SC}(t + \Delta t) = E_{SC}(t) + \eta \Delta t P_{SC} - \xi E_{SC}(t) \tag{4}$$

where E_{SC} is energy stored in SC, Δ is charging/discharging efficiency, ξ is self-discharge rate, and P_{SC} is power input/output to/from SC. P_{SC} is positive during the charging phase and negative during the discharging phase [8].

During times of high renewable energy production, excess energy may be stored in a micro-grid and then used to power homes and businesses during times of low production. To accurately estimate energy, a charge assessment is required. Battery state-of-charge (SOC) may be calculated over time using the formula (5).

$$\frac{SOC(t)}{SOC(t-1)} = \int_{T}^{T-1} \frac{P_{SC}(t)\eta}{V_{bus}} dt \tag{5}$$

The variables in this equation are the battery's input/output power ($P_{SC}(t)$), the bus voltage (V_{bus}), and the battery's round trip efficiency (η_{batt}). The battery is being charged if $P_{SC}(t)$ is positive; otherwise, it is being discharged [8].

E. Dual Converter Modeling

Every technology that operates on a direct current (DC) must convert to an alternating current (AC) power source. Converting the direct current (DC) from solar photovoltaic panels and batteries to alternating current (AC) is essential. To get the power output of the converter P_{inv} the following formula is used.

$$P_{inv}(t) = P_L^m(t)/\eta_{inv} \tag{6}$$

In the equation (6), the size of the converter is determined by the peak load $P_L^m(t)$ and η_{inv} represents the efficiency of the converter [9].

III. Energy Management System

An energy management system (EMS) is a crucial component of a micro-grid that incorporates photovoltaic (PV), wind, and biomass renewable energy sources. The EMS is responsible for controlling and optimizing the operation of the micro-grid to efficiently and cost-effectively meet the system's electricity demand. In a micro-grid with PV, wind, and biomass energy sources, the EMS must account for the variable output and the availability of these resources. For instance, just as PV output is dependent on the amount of available sunshine, wind output is based on wind speed and direction. The EMS must also account for potential variations in the production of biomass-based energy sources, including the availability of feedstocks and the efficiency of conversion processes. In addition to controlling renewable energy sources, the EMS must also take the grid link into account. When a micro-grid is connected to the grid, it can sell excess electricity back to the system or purchase electricity from the grid to satisfy demand. In order to reduce the overall cost of electricity for the micro-grid, the EMS must identify the ideal balance between these possibilities. Besides, there are super capacitor batteries for storing and distributing the electricity produced from the micro-grid. Overall, the energy management system plays a significant role in ensuring the reliable and cost-effective functioning of a micro-grid consisting of PV, wind, and biomass energy sources, as well as a grid link.

IV. Social spider optimization algorithm

The social spider optimization (SSO) method is used to determine the ideal capacity of a micro-grid in order to reduce net present cost and LCOE. The optimization challenge is becoming increasingly complicated as the number of micro-grid components increases. Social spiders cooperate to reach food sources. Vibrations from a potential food source are picked up by the spiders and analyzed to help them locate it. The SSO optimization approach is used to get hyper-dimensional spider webs, which are used in SSO to find the best solution. The web also carries the spider's vibrations. The objective function's fitness is determined by the spider's ability to find food at each web location. Here, the major goal of this optimization is to reduce the present value cost of the proposed micro-grid. Therefore, ideal spider web solutions will indicate the amount of capacity needed to operate the system at the lowest possible cost based on solar insolation data, wind speed data, and load demand data. Since the spots outside the web are limited by the optimization issue, spiders can freely move around the web but cannot leave it. When a spider moves, the web vibrates. By receiving the vibration, other spiders can get the information [10]. If a set of solutions cannot supply load demand using renewable solutions and biomass, SSO automatically ignores them by penalizing fitness. Fig. 3 shows the Social spider optimization algorithmic flowchart.

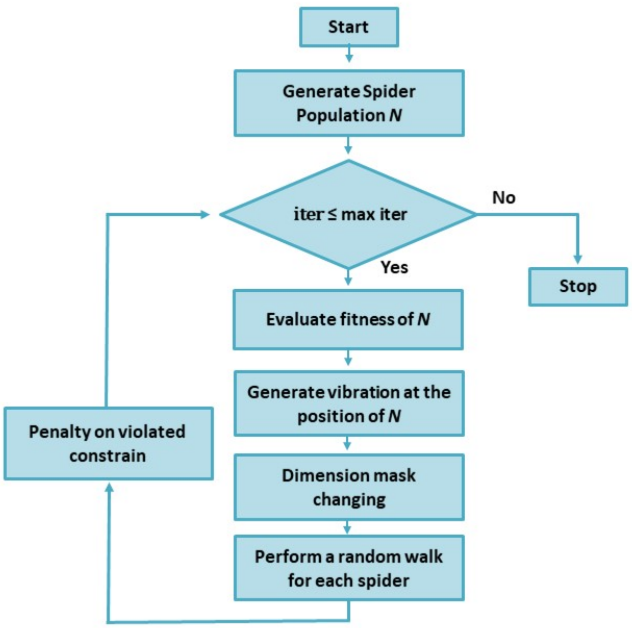


Fig. 3: Social spider optimization flowchart

V. Formulation of Optimization Problem

The final goal of the research was to develop a micro-grid system that could operate with little expense and upkeep. Biomass, solar panels, wind turbines, super capacitor batteries, and other forms of energy storage are essential, and their number and scale are carefully considered.

This study determined the hybrid system's minimal NPC value without affecting performance. Number of wind turbines, solar panel area, super capacitor battery capacity, and biomass rating all have an impact on the configuration. The most cheap ASC may meet all needs and allow cost-benefit analysis. The objective function includes capital equipment, depreciation, and operations and maintenance expenditures. Construction and extensive repairs are common capital expenditures. Minimize the following function.

$$ASC_{min} = Minimum(P_{sol}C_{sol} + N_{wt}C_{wt} + P_{bio}C_{bio} + N_{sc}C_{sc} + P_{inv}C_{inv}) \tag{7}$$

In the equation (7), C_{sol}, C_{wt}, C_{sc}, and C_{inv}, respectively, represent the costs of solar PV panels (per kW), wind turbines (per kW), super capacitor batteries (per unit), and inverters (per kW), in that order. The rating of biomass is represented by the symbol P_{bio}, whereas the cost of biomass is represented by the symbol C_{bio}. P_{inv} is a symbol that represents the inverter's rating, and it may be found in parentheses after the symbol.

As a result of rigidly following to a set of restrictions, the objective function is minimized to the greatest extent feasible.

$$1 \leqslant P_{sol} \leqslant P_{sol_{max}} \tag{8}$$

$$1 \leqslant N_{wt} \leqslant N_{wt_{max}} \tag{9}$$

$$1 \leqslant P_{bio} \leqslant P_{bio_{max}} \tag{10}$$

$$1 \leqslant N_{sc} \leqslant N_{sc_{max}} \tag{11}$$

$$SOC_{min} \leqslant SOC \leqslant SOC_{max} \tag{12}$$

The maximum rating of solar PV panels is represented by the value $P_{sol_{max}}$, the maximum number of super capacitor batteries by the value $N_{sc_{max}}$, the maximum number of wind turbines by the value $N_{wt_{max}}$, and the maximum rating of biomass by the value $P_{bio_{max}}$.

The levelized cost of energy (LCOE) and the demand for maximum dependability are weighted against one another to determine the best configuration. The LCOE measures how much it costs to run a building per kilowatt-hour of energy produced [11]. It can be expressed as the equation (13).

$$LCOE = \frac{ASC + Grid_{Brought} - Grid_{Sold}(\$/year)}{\text{Usable energy delivered (kWh/year)}} \tag{13}$$

The capital cost, replacement cost, operating and maintenance cost, and expected lifespan of each micro-grid component are detailed in Table I.

TABLE I: Components Parameters of Optimisation [12]

Component Name	Per Unit Capacity	Capital Cost	Replacement Cost	Operation & Maintenance	Lifetime (Years)
PV Panel	1 kW	1500 ($)	-	50 ($/yr)	20
Wind Turbine	1 kW	1300 ($)	1200 ($)	200 ($/yr)	20
Boimass System	1 kW	4000 ($)	-	150 ($/yr)	20
Super Capacitor Battery	7 kWh	1250 ($)	1100 ($)	20 ($/yr)	10

The completed micro-grid will sell excess energy to the utility grid if needed. The conventional power grid will cover the gap if the final micro-grid cannot produce enough electricity hourly. Table II displays current market pricing for the featured design.

TABLE II: Bangladesh Per Unit Electricity Prices [13]

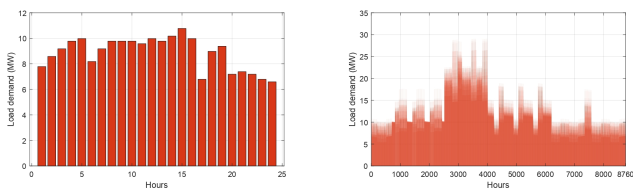
Operation (Per Unit)	Price ($ /kWh)
Energy Brought from Grid	0.079
Energy Sold to Grid	0.079

VI. Analysis Condition

In Halishahar, the major focus for the yearly basic load consumption model estimate was in Wards 11, 25, and 26. Latitude and longitude of *22°19’* and *22°20’* North and *91°45’* and *91°48’* East are the boundaries of Halishahar area.

A. Load Model

We used data collected by the Power Grid Company of Bangladesh (PGCB) to determine the average daily power usage for the selected area [14]. Electrical consumption data is gathered by the Power Grid Company of Bangladesh Ltd. at the Halishahar substation in North Patenga.



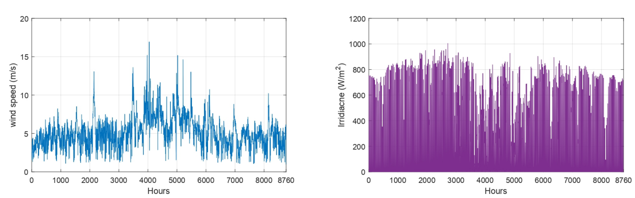
(a) 24 Hours Load (b) Annual Load

Fig. 4: Electrical Load Demand (Hourly)

Fig. 4a depicts the hourly load demand in Halishahar, whereas Fig. 4b shows the annual load demand for the area. The area is predicted to need 1,07,150 MWh of electricity per year, according to the load calculation.

B. Renewable resource data

Hourly data collection on Halishahar’s renewable resources is necessary before moving on. Data about local resources was culled from NASA’s Power database [15].



(a) Wind Speed (b) Solar Irradiance

Fig. 5: Annual Solar and Wind Data (Hourly)

Fig. 5a displays daily averages of solar irradiance at Halishahar, whereas Fig. 5b displays daily averages of wind speed.

VII. Results & Discussions

All possible adjustments based on the given parameters are simulated using the SSO algorithm method to system modeling in order to satisfy the load requirement. Power generated by the micro-grid will be stored in super capacitor batteries and released to meet load demands as they arise. If the system is unable to meet the load requirements, the traditional grid will be connected as a backup. Hourly surplus energy will be sold back into the power grid as Sell.

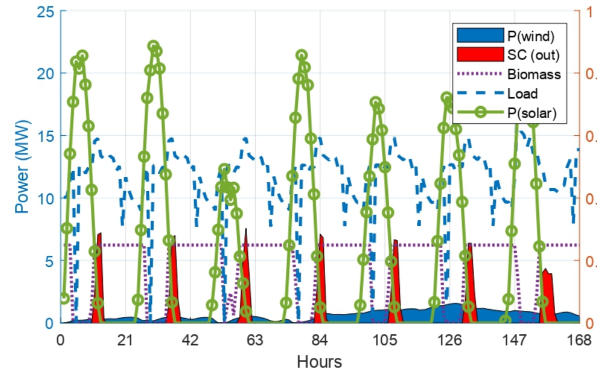


Fig. 6: Energy Generation Comparison

The hourly production of renewable energy for 1 week is compared in Fig. 6. The majority of our power comes from solar sources at this point. The generation from the wind farm is the least efficient of all of our many types of electricity sources. Aside from that, the production of biomass has a significant influence on this power system.

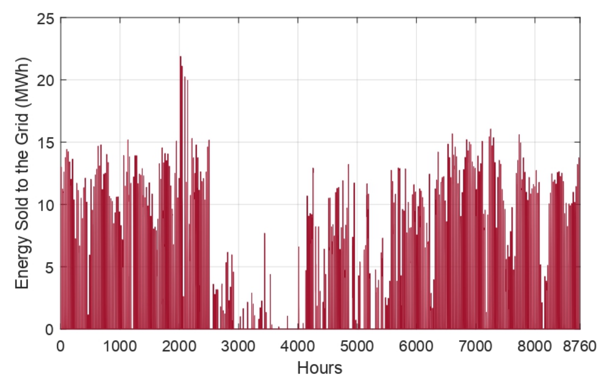


Fig. 7: Energy sold out to the grid

The optimization result shows that the micro-grid system for Halishahar generates surplus energy during certain hours after meeting the load requirement, which is then exported to the main power grid. Throughout the course of a year (8760 hours), our micro-grid’s sold energy is shown in Fig. 7.

Fig. 8 illustrates a monthly scenario that represents the total generation, total load consumption, and the trading of energy with the grid. Using this figure, it is feasible for us to compute the entire quantity of renewable energy that is created as a result of the conversion of sources such as the solar, the wind, and biomass. It is necessary to take power from the grid in order to make up the gap between the total monthly demand for energy and the amount of energy that can be generated from renewable sources because the total monthly demand for energy is greater. Once more, we are able to view the energy that has been transferred to the grid from our system. This is the hourly surplus of energy that cannot be stored in the batteries.

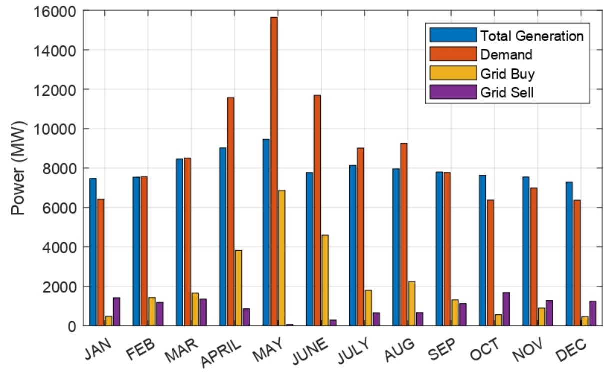


Fig. 8: Total generation, load demand and grid trading scenario

The SSO algorithm optimizes the results of each model while decreasing the NPC (Net Present Cost) and LCOE (Levelized Cost of Energy) of the system. SSO minimizes the system's NPC and LCOE to get the best possible results for each model.

TABLE III: Final Design of Micro-grid

Type	Item	Quantity
Installed Capacity (kW)	Solar Panel	30,290
	Wind Turbine	1,701
	Biomass System	10,380
	Super Capacitor Battery	3,333
Annual Energy (MWh/yr)	Renewables	96,059
	$\text{Grid}_{\text{Sold}}$	26,069
	$\text{Grid}_{\text{Brought}}$	11,809
Cost Analysis ($)	Net Grid Sell	0.932M
	Net Grid Buy	2.059M
	Net Present Cost	13.63M
LCOE ($/kWh)		**0.127**

SSO developed the micro-grid with annual renewable generation and biomass system. Table III summarizes installation capacity, annual energy and cost. This micro-grid's levelized cost of energy was 0.127 $/kWh.

VIII. Conclusions

In this study, we examined several methods for determining the total output of a hybrid renewable energy system that is tied into the utility grid. Controlling the flow of power to a specific location is the job of an energy management system. The system includes solar PV cells, wind turbines, biomass, and super capacitor batteries. It was established that the micro-grid production system's output was enough to fulfill the load demand in the designated area. Investing in and maintaining the facility would be much cheaper if the greatest feasible micro-grid components were used. It is possible that this technology will be further developed and used in many contexts during the next years as the need for energy increases. Since the SSO approach is efficient at resolving issues of this kind, and the hybrid system has a negligible influence on the natural world, it is well-suited to this type of application.

The project's annual earnings and expenses were projected. We had to purchase power from the grid since the system's production wasn't enough to fulfill the area's consistent load requirement. Sometimes we had a surplus to Sold back. The model encounters many restrictions whether applied to the actual world or a simulation. The central generator for the PV system is also present. Biomass has great potential despite its high cost. Trash is usually burnt immediately to create combustion gas, which is utilized to generate energy. The system's LCOE of 0.127 $/KWh for renewable energy is competitive. We used the SSO approach to gather this information on our proposed micro-grid. In the future, we may try other algorithms like Artificial Bee Colony, Particle Swarm Optimization, Genetic Algorithm, and others.

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